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# Characterization of Long-Term Toxic Emissions from Municipal Sludge Incineration - Project Plans and Status

Radian Corp., Research Triangle Park, NC

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# CHARACTERIZATION OF LONG-TERM TOXIC EMISSIONS FROM MUNICIPAL SLUDGE INCINERATION -- PROJECT PLANS AND STATUS

by

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# CHARACTERIZATION OF LONG-TERM TOXIC EMISSIONS FROM MUNICIPAL SLUDGE INCINERATION -- PROJECT PLAN AND STATUS

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## ABSTRACT

Emissions testing is to be conducted on four municipal sludge incinerators over longer periods of time than normal. Three multiple hearths and one fluid bed are to be included and testing is scheduled during April, May, and June, 1987. Measurements are planned over the short term under smooth compliance testing type conditions and over longer times in order to include typical varying conditions. Variations that might be encountered include startup, shutdown, temperature excursions, feed rate changes, and downtime during maintenance on part of the dewatering system. Metals and organics are both of interest, including products of incomplete combustion. Closing of material balances is desired where possible.

The smooth operation results would be used in conjuction with regulations being proposed under Section 405 of the Clean Water Act. Data on varying conditions would permit the comparison of smooth operations and typical variations. We could then see how the combination of both types of operation, which characterizes the average, differs from "best" operation likely encountered in compliance testing. We suspect that the present compliance testing conditions are lower in emissions than on the average. The comparisons could point the way to more realistic testing and regulating for the future.

## INTRODUCTION

The EPA Office of Water Regulations and Standards (OWRS) is in the process of setting standards for municipal sludge incineration under Section 405 of the Clean Water Act (CWA). The deadline for issuing proposed regulations for public comment is now August 31, 1987. The project outlined here will provide direct support for those regulations. Many of the pollutants of concern may be conveyed by industrial wastewater discharges to a publicly owned treatment works and thence to the municipal sludge. Hence, this study is also of direct interest to OWRS's Industrial Technology Division in its regulation of industrial wastewaters under Section 307 of the CWA.

The multiple-hearth sludge incinerator is the most common one used in the field with fluid bed incinerators becoming increasingly popular. There are currently about eight times as many multiple-hearths as fluid beds. Data on emissions from these types of incinerators are desired as back-up information for implementing the Section 405 standards. In addition, sludge incinerators are viewed as poorly operated with high potential to exceed the New Source Performance Standard (NSPS) and are being considered under National Emissions Standards for Hazardous Air Pollutants (NESHAP's). Both of these latter standards are authorized under the Clean Air Act and are the responsibility of EPA's Office of Air Quality Planning and Standards. The EPA Office of Policy, Planning and Evaluation has also expressed interest in the proposed work.

The usual testing on incinerators has been for short periods of time and likely for periods of "best" operation when emissions are at a minimum. What is desired is to test the incineration process over a longer time of operation, to include both the more smooth "best" operation and also varying conditions, and to characterize emissions more completely. Varying conditions of interest include startup, shutdown, temperature excursions, feed rate changes, and downtime during maintenance on part of the dewatering system. Metals and organics are of particular interest, including products of incomplete combustion (PIC's). Where possible, closing of material balances is desirable.

The work is being conducted by Radian Corporation under contract to EPA's Water Engineering Research Laboratory with additional support provided by the EPA Office of Water Regulations and Standards. Data collection is scheduled for April, May, and June, 1987.

## SLUDGE PRODUCTION

Major processes involved in production and treatment of muncipal wastewater sludges include sedimentation, aerobic and anaerobic digestion, chemical and thermal conditioning, and dewatering. From the standpoint of incineration, the most important aspect of these related processes is their impact on the moisture and energy content of the sludge. Some of the processes which improve the dewatering characteristics of wastewater sludge can also reduce the proportion of volatile elements to inert materials. Sludge treatment processes, such as anaerobic digestion, can significantly lower the energy content of the sludge.

Most sewage sludges undergo a variety of

treatment prior to the final conditioning and dewatering steps. Since sludge conditioning and dewatering are integral to the overall incineration process it is important that prior sludge treatment steps be known and their effects understood before embarking on this test program. Test sites have been sought that incinerate a mixed primary and secondary sludge that has been thickened and chemically conditioned. Primary sludge results from sedimentation of raw wastewater and secondary sludge results from sedimentation after aerobic biological treatment. Such a mixture commonly results from currently accepted wastewater treatment technology.

All sludges are dewatered before incineration to reduce water content of the sludge cake to a range of about 60 to 85 weight percent. Dewatering is a critical step in the process of sludge incineration, since it reduces the thermal demand on the incinerators. Vacuum filtration, filter presses, belt filters, and centrifugation are the most widely used sludge dewatering technologies, although numerous other processes are available. The National Emissions Data Source (NEDS) data base lists nearly 1,200 vacuum filters, 242 centrifuges, 151 filter presses, and 36 "other" dewatering devices as currently in use at sewage treatment plants. The use of the relatively new belt press system is increasing.

## INCINERATION PROCESSES

### Multiple-Hearth Incineration

The basic multiple-hearth incinerator or furnace (MHF) design is nearly a century old, having been initially developed for roasting of mineral ores. An air-cooled variant of the original Herreshoff design has been used for incinerating sewage sludge since the 1930's.

Dewatered sludge is fed into the periphery of the top hearth. The motion of rabble arms rakes the sludge toward a center shaft where it drops through holes located near the inner edge of the hearth. In the next hearth the sludge is raked in the opposite direction and drops at the outer edge of the hearth to the next hearth below. This process is repeated in all of the subsequent hearths. The effect of the rabble motion is to break up solid material to allow better surface contact with heat and oxygen, and to maintain a sludge depth of about one inch in each hearth when operating at the design sludge flow rate.

Ambient air is first ducted through the central shaft and its associated rabble arms. A portion, or all, of this air is then taken from the top of the shaft and recirculated into the lowermost hearth as preheated combustion air. Shaft cooling air which is not circulated back into the furnace is ducted into the stack downstream of the air pollution control devices. The combustion air flows upward through the drop holes in the hearths, countercurrent to the flow of the sludge, before being exhausted from the top hearth. Provisions are usually made to inject ambient air directly into one of the middle hearths as well.

### Fluidized-Bed Incineration

Since its original development as a method for recovering catalysts in the oil refining industry, fluidized-bed technology has been applied to a wide range of industrial processes. The first fluidized-bed reactor designed specifically for incineration of sewage sludge was installed in 1961 in Lynnwood, Washington.

Dewatered sludge is fed into the lower portion of the furnace. Air injected through nozzles at pressures ranging from 3 to 5 psig simultaneously fluidizes the bed of hot sand and the incoming sludge. Temperatures of 1,400 to 1,700°F (760 to 930°C) are maintained in the bed. Residence times are on the order of 2 to 5 seconds. As the sludge burns, fine ash particles and some sand are carried out the top of the furnace. Sand make-up requirements are on the order of 5 percent for every 300 hours of operation.

The overall process of combustion of the sludge occurs in two zones. Within the bed itself (zone 1) evaporation of the water and pyrolysis of the organic materials occur nearly simultaneously as the temperature of the sludge is raised rapidly. In the second zone, (freeboard area) free carbon and combustible gases are burned. The second zone functions essentially as an afterburner

## FURNACE EMISSIONS CHARACTERISTICS

Particulate emission rates directly from the furnace and prior to pollution control can vary widely depending on the type of incinerator, the volatiles and moisture content of the sludge, and the overall operating practices employed. Direct particulate emission data for multiple-hearth incinerators from the most recent review of the NSPS for sewage sludge incinerators showed a range from 5 lb/dry ton (2.5 g/Kg) sludge input to over 450 lb/ton(225 g/Kg). The average emission rate for the multiple-hearth incinerators was 89 lb/dry ton (44.5 g/Kg) of sludge.

Sewage sludge incinerators also emit potentially toxic trace elements. Direct emissions are dependent on sludge composition and the site-specific operating conditions. Bennett and Knapp[1] have identified the emissions of trace elements and of specific organic constitutents. Emissions controlled by a wet scrubber depend also on the performance of the wet scrubber and the distribution of trace metals among the various particle size fractions. There is also some evidence that organics in the scrubber water may be stripped out of the scrubber water and added to the scrubber emission stream.

## TYPICAL EMISSIONS CONTROLS

Incinerators that have begun operating over the past 10 years commonly employ combination venturi/impingement-tray scrubbers to control particulate emissions. However, prior to that time the predominant control technology appied to multiple-hearth incinerators was an impingement tray scrubber. Impingement-tray scrubbers alone offer the advantage of operating at a total pressure drop in the range of 6 to 9 inches of water (multiply by 2.54 to express as centimeters of water). Combination venturi/impingement-tray scrubbers are operated at total pressure drops of approximately 30 inches of water. The NSPS

standard could likely be achieved at pressure drops of less than 30 inches of water, although higher pressure drops are commonly employed to account for wide variations in the particulate loading at the scrubber inlet.

Over the past 10 years there has been a distinct trend toward the nearly exclusive use of combination venturi/impingement-tray scrubbers to control emissions from incinerators. Prior to 1978 only about 20 percent of multiple-hearth incinerators were equipped with venturi/impingement-tray scrubbers. However, all but 3 of the 17 multiple-hearth incinerators installed after 1978 use this technology. Fluid-bed incinerators use similar control technology.

## TEST OBJECTIVES

There are five major objectives of this test program. These are to:

(1) determine long-term (i.e., combined average smooth and varying operation) emissions;

(2) develop long- and short-term emission rates relating sludge composition to stack emissions;

(3) determine if smooth conditions test data can be used to accurately approximate long-term emissions;

(4) determine the efficiency of the control devices in removing metal and organic emissions; and

(5) develop cause and effect relationships between incinerator operation and emissions.

The major objective of the test program is to determine the long-term emission characteristics of sewage sludge incinerators as a function of incinerator operating parameters and sludge composition. Although one fluid bed will be included, the multiple hearth likely will have more serious emissions problems and is being emphasized.

Due to a variety of factors, the operating conditions of incinerators are subject to wide and frequent variation. These variations in operating conditions have the potential to cause equally wide fluctuations in emissions of toxic air pollutants. However, all available emission test data for sewage sludge incinerators have been collected over relatively short periods of time and during periods of "best" operation. As a result, the available data may not provide an accurate indication of the long-term environmental impacts associated with the incineration of sewage sludge. Similarly, insufficient data are available to determine which operating conditions have the most significant impact on emissions. In response to these uncertainties, the test program described here is intended to generate data that will more accurately reflect the emissions from incinerators over the range of operating conditions that are typically experienced during day-to-day operation.

Secondly, it is the goal of the test program to develop long- and short-term emission rates for incinerators. The stack emissions of trace metals and organics will be evaluated as a function of the metals and organic content of the sewage sludge. Long-term emission rates will be developed for normal (i.e., average) operation of the multiple-hearth incinerator. In addition, short-term emission rates will be developed from data collected when the incinator is operating under smooth "best" conditions. The ultimate result will be the prediction of trace metals and organic emissions based on an assessment of the sewage sludge quality.

The extent to which smooth "best" operation emissions predict the actual long-term emissions will also be evaluated. Since all available test data for sewage sludge incinerators were collected during smooth operation, the relationship between these data and emissions during average normal operation will be a valuable asset for setting emission standards.

To the extent practicable, the emission and operating data collected during the test program will also be used to identify the specific mechanisms that control the rate of release of air pollutants from incinerators and determine the removal efficiency of the emission control devices. For example, it is not known whether increases in emissions of trace metals are caused primarily by increases in the mass loading to the emissions control device or by changes in the distribution of the metals within different particle size fractions. Moreover, it is not known whether changes in either mass loading or particle size are moderated by temperatures, exit gas velocity, sludge quality, or some combination of factors. Data on cause-effect relationships can be used to define operating practices that will minimize emissions and to define appropriate monitoring programs.

For steady-state test runs, determination of whether or not the incinerator is operating under the required parameters will be based on the following:

(1) comparison of the real time operating data with the smooth operating values determined during prior testing;

(2) continuous monitoring of time based plots of the operating data;

(3) close observation of operator action;

(4) reports from operators about operating problems that alert the control room observer to potential transients.

After each test day where smooth test runs are attempted, the operating data will be reviewed to determine if the required parameters for steady-state were met. If not, then the test run will be considered a "normal" operation test, and the additional steady-state test runs will be performed.

## POLLUTANTS TO BE MONITORED

Existing data are insufficient to determine whether, and which, specific categories of pollutants may be relatively more or less sensitive to

fluctuations in incinerator operating conditions. However, because upsets in incinerator operations often result in major changes in the temperature profile within the incinerator, it is expected that emissions of both inorganic (especially metals) and organic species will be sensitive to changes in operating conditions. Therefore, the test program is designed to be comprehensive with respect to the categories of pollutants that will be measured during the tests.

The specific inorganic elements and organic compounds which will be analyzed during this test program are included in Table 1. This list includes elements and compounds which are of particular interest to the Office of Water Regulations and Standards (OWRS) and the Office of Air Quality Planing and Standards (OAQPS). Some of the compounds were included in this list because there was evidence that they were present in the emissions from previous testing on sewage sludge incinerators. This list may be edited prior to analysis pending the results of combustion tube analysis to be done by the University of Dayton Research Institute (UDRI). This analysis is described in a later section of this paper.

## SAMPLING LOCATIONS

Two separate test plans will be used during this test program. At multiple-hearth site A (MH-A) and the fluidized-bed combustor (FBC) sites, sampling may be conducted only at the outlet of the control device. The urgency of the test program demands that data be collected as soon as possible and there may not be time for installation of inlet test ports. Continuous emission monitors (CEMs) will be located at the control device inlet if possible for the purpose of monitoring process operation. Testing at the outlet is definitely required to accurately measure the amount of emissions which are actually released to the atmosphere during the various test conditions. The reasons for this are:

(1) It is very difficult to predict scrubber performance under transient and upset conditions; therefore, data taken only at a scrubber inlet would be of limited use.

(2) It is much more difficult to measure total particulates accurately during varying conditions at the scrubber inlet versus the outlet. If only inlet data are available, the error bounds in the measurements may make comparison between smooth and varying conditions meaningless.

At the other two multiple-hearth sites, MH-B and MH-C, testing will be performed at both the inlet and outlet of the control device. The data collected at the inlet will identify the effects of process operating conditions on direct emissions characteristics. The outlet samples will identify the actual emissions from the sewage sludge incinerator. In addition, the role of the control device in reducing emissions can be evaluated when simultaneous inlet/outlet samples are collected. At site MH-C parametric testing of an afterburner will also be conducted.

Sludge feed samples will be collected during each test. During sampling for semi-volatile and volatile organics, samples of the scrubber water influent will be collected to determine if it contributes to the organic stack emissions. Sludge feed, ash, and scrubber water (influent and effluent) samples will be collected during smooth conditions test runs and measurements of ash and scrubber water flow rates will be taken at sites MH-B and MH-C. Analysis of these samples, along with the flue gas emissions measurements, will allow material balances to be calculated.

## TEST SCHEDULE

Ideally, three test runs should be completed for each test condition. Data from at least three runs are generally required to calculate averages for compliance testing. Essentially, there will be two incinerator operating conditions under which sampling will be conducted: smooth and normal. At site MH-C, testing will be conducted during startups/shutdowns and with the afterburner on and off.

The proposed test schedule for the MH-A and fluidized-bed combustor (FBC) sites will each require five days of sampling plus two days for setup/teardown. All smooth operations samples will be collected during one test day. The remainder of the tests will be conducted under normal plant operating conditions.

The proposed test schedule for site MH-B will have testing at both the inlet and outlet of the control device. These tests will require seven days of sampling plus two days for setup/teardown. During four of the test days the incinerator will be operated at normal conditions. The other three test days will be under smooth operating conditions.

The proposed test schedule for site MH-C will include parametric testing on the afterburner. In addition, testing will be performed during startup and shutdown of the sewage sludge incinerator. Testing will be performed on ten days with an additional two days designated for setup/teardown.

## SITE SELECTION

A list of potential multiple-hearth incinerator test sites was developed from in-house data sources which included:

(1) Multiple-hearth units considered for the Tier 4 Survey of the National Dioxin Study;

(2) New Source Performance Standards (NSPS) Review Data;

(3) Muncipal Waste Combustion Study;

(4) Multiple-hearth incinerator sites supplied by Eastern Research Group; and

(5) Previous site contacts/visits.

This list of potential test sites, along with candidate sites suggested by EPA, was computerized and sorted by incinerator capacity (dry tons/day). A smaller list containing the candidate sites suggested by EPA and the facilities that contained

more than one medium sized (approximately 20 to 100 dry tons/day) multiple-hearth incinerator was compiled and as many as possible were contacted by telephone. Information collected included: source information, incinerator characterization, sludge, supplemental fuel, incinerator operating characteristics, control device design and operation, testing considerations, and status (of facility).

The following criteria were then used to evaluate the sites contacted with the intent of selecting 6 sites to visit (one site with an afterburner was desirable):

- The site should not be very large because large facilities generally operate continuously.
- The site should shut-down and start-up at least once a week on a scheduled basis.
- There should be no intermediate sludge storage between the dewatering device and the incinerator because this is not typical practice.
- A single furnace should be fed by two or possibly three dewatering devices where one dewatering device is shut down occasionally for cleaning or maintenance.
- The site should have adequate sampling locations, both before and after the control device.
- The site should have a continuous record of the incinerator sludge feed rate.
- The preferred air pollution control device is a variable throat venturi followed by a plate column scrubber.
- The scrubber liquid should consist of secondary wastewater treatment or final plant effluent (primary effluent has contributed to high organics in past tests).

Based on data gathered during the site visits, sludge analysis data, and from data previously gathered, three final sites were chosen for testing. The sites which were chosen for testing are presented in Table 2 according to general site characteristics which make them desirable for this testing program. The overall operation is based on the number and duration of process variations over a specified time period. Sampling will be conducted at the inlet and outlet of the control device at the MH-B and MH-C sites because they are equipped with venturi/impingement tray scrubbers which are more efficient than impingement tray scrubbers alone.

One additional site, a fluidized-bed combustor (FBC), was chosen later for testing. When the site selection process was initially started, FBC incinerators were not considered. However, one has been included now for the sake of completeness. The same general guidelines used to choose the multiple-hearth incinerator sites were used in choosing an FBC site.

## COMBUSTION TUBE ANALYSIS OF SLUDGE

Specific products of incomplete combustion (PIC's) that may be formed from organic precursors during sludge incineration have not previously been determined during full-scale incinerator tests. The organic emissions from an incinerator are a function of the sludge characteristics, incinerator operating efficiency, and emission control device efficiency. To determine the most likely organic emissions resulting from sludge incineration, bench-scale thermal decomposition testing will be performed by the University of Dayton Research Institute (UDRI) on a sludge sample from each of the four selected sites. The thermal decomposition testing will have two phases. The initial phase will involve testing a sludge sample from each of the four test sites to determine the most likely organic emissions. These sludge samples will be taken during the pretest site survey and the testing will be completed before any of the test samples are analyzed. During this initial phase the top 20 peaks will be identified and semi-quantitative results on yields will be provided. The results from the UDRI testing will be compared to the specific organic compounds which are presently targeted for analysis (see Table 1). If the UDRI testing detects a significant quantity of an organic compound which was not included in Table 1, then that compound will be included in the group of compounds for analysis for this test program.

Phase II of the UDRI thermal decomposition testing will involve testing the actual sludge which was incinerated during the emission testing at each site. During this phase, analysis will be conducted for the organic compounds specified in the site-specific sampling and analysis plan. The results of this phase of the UDRI testing will be analyzed in relation to the actual emission results to see if any correlation exists.

UDRI will use their System for Thermal Diagnostic Studies (STDS). The STDS incorporates a bench-scale thermal decomposition unit with an in-line gas chromatograph-mass spectrometer (GC/MS) for product analysis. The bench-scale thermal decomposition unit consists of a CDS, Inc. pyroprobe followed by a high temperature reactor. Using this design, experiments can be conducted which yield products that might typically originate in the combustion zone of an incinerator or desorption/degradation products more typical of those which would evolve from the drying zone. During each phase, the experiments will be conducted under three separate temperature schemes and in two different atmospheres, nitrogen (pyrolysis) and air (combustion). The residence time in the reactor will be 2.0 seconds for each test. The test temperatures proposed for this project are 316°C, 538°C, and 871°C; these are temperatures typical of furnace operation.

## CURRENT PROJECT STATUS

The current status of the project will be reviewed at the time of the Conference, along with the presentation of available data and preliminary conclusions.

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REFERENCE

1. Bennett, R., and K. Knapp, "Characterization of Particulate Emissions from Muncipal Wastewater Sludge Incinerators." EST, 16, No. 12, 1982, pp. 831-836.

TABLE 1. SPECIFIC ELEMENTS AND COMPOUNDS OF INTEREST

| METALS[a] | PCBs AND PESTICIDES (Cont'd) |
|---|---|
| Arsenic | PCB-1221 |
| Beryllium | PCB-1232 |
| Cadmium | PCB-1248 |
| Chromium | PCB-1260 |
| Lead | PCB-1016 |
| **VOLATILES[b]** | **SEMI-VOLATILES[c]** |
| Acrylonitrile | Acid Compounds |
| Benzene | |
| Carbon Tetrachloride | 2-Chlorophenol |
| Chlorobenzene | 2,4-Dichlorophenol |
| Chloroform | 2,4-Dimethylphenol |
| 1,2-Dichloroethane | 2,6-Dinitro-o-cresol |
| Trans-1,2-Dichlorethane | 2,4-Dinitrophenol |
| Ethylbenzene | 2-Nitrophenol |
| Ethylene Oxide | 4-Nitrophenol |
| Methylene Chloride | p-Chloro-m-cresol |
| Tetrachloroethylene | Pentachlorophenol |
| Toluene | Phenol |
| 1,1,1-Trichloroethane | 2,4,6-Trichlorophenol |
| Trichloroethylene | |
| Vinyl Chloride | Base/Neutral Compounds: |
| PCBs AND PESTICIDES | Benzo(a)pyrene |
| | bis(2-ethylhexyl)phthalate |
| Aldrin | 1,2-Dichlorobenzene |
| Chlorodane | 1,3-Dichlorobenzene |
| Dieldrin | 1,4-Dichlorobenzene |
| Toxaphene | Perchloroethylene |
| PCB-1242 | 1,2,4-Trichlorobenzene |
| PCB-1254 | |

[a] These metals are of specific interest to OWRS. Arsenic, cadmium, and lead will be analyzed by AA, others by the inductively coupled argon plasma (ICAP) method.

[b] Vinyl chloride, chloroform, carbon tetrachloride, and tetrachloroethylene are of specific interest to OWRS. The remaining volatiles are currently under review as NESHAP canadidates and are therefore of interest to EPA as toxics.

[c] Benzo(a)pyrene and bis(2-ethylhexyl)phthalate are of specific interest to OWRS. An initial GC/MS scan will be performed according to EPA Method 625. If any of the target pesticides or PCB's are found during the GC/MS method, the sample will be further analyzed for pesticides and PCB's by OSW Method 8080.

TABLE 2. MULTIPLE-HEARTH SITES SELECTED FOR TESTING AND GENERAL CHARACTERISTICS

| Site | Overall Operation | Control Device Type | Type of Sampling |
|---|---|---|---|
| MH-A | Average | Impingement Tray Scrubber | Outlet of Control Device |
| MH-B | Average | Venturi/Impingement Tray Scrubber | Inlet and Outlet of Control Device |
| MH-C | Better than Average | Venturi/Impingement Tray Scrubber | Inlet and Outlet of Control Device |